Quarterly Progress Report

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FUNDAMENTAL STUDIES OF THE METALLURGICAL, ELECTRICAL, AND OPTICAL PROPERTIES OF GALLIUM PHOSPHIDE

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Work Performed By

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PROJECT 5115: SEMICONDUCTOR DEVICES FOR HIGH TEMPERATURE USE

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The purpose of this project is to prepare power rectifiers and solar batteries which will operate at temperatures up to 500°C. During this quarter, Schottky barrier diodes were formed by nickel evaporation upon undoped GaP grown by vertical liquid epitaxy, work upon a method to alloy ohmic contacts in the vacuum system used for the metal deposition was started, and an analysis of some device characteristics was made.

Diode Construction

As stated in the last quarterly report, some success has been achieved in the hydrogen atmosphere growth of undoped GaP using the vertical liquid epitaxial configuration. For example an epitaxial layer approximately 100 microns in thickness was grown upon a tellurium doped GaP seed.

To evaluate the quality of that particular material, an array of nickel Schottky barrier diodes was formed. From depletion capacitance measurements, the carrier concentration of the undoped GaP is approximately 3×10^{15} cm^{-3}. Furthermore, eight of the diodes tested had reverse breakdown voltages in excess of 100 volts, with two diodes having breakdown voltages greater than 200 volts. These results are especially encouraging in two respects. First of all, the results confirm the data previously obtained with vapor grown material.[1] However, the liquid epitaxial system should be capable of producing controlled thin layers more easily and with fewer crystal imperfections than a vapor one, and therefore is presently preferred. Secondly, the carrier concentration stated is as low as that previously obtained with the vapor system and represents better than an order of magnitude improvement over earlier liquid epitaxial efforts. Further work will continue in this area to produce the thin layers needed.

The problem of producing reliable ohmic contacts of low resistance still remains. A new approach has been taken in this area. The "mini-vac" sputter-ion system previously described has been modified to allow alloying in place concurrently or immediately following the deposition of the contact material. The modification consists of the addition of a substrate heater and a thermocouple monitoring system in the vacuum chamber and the construction of an external current power supply. This work has just been completed and the new system will be tested this coming quarter.

Device Analysis

Even though alloying in place may produce reliable ohmic contacts, low total series resistance for the device is also required. Therefore, a simple analysis was made to investigate the relative magnitudes of the contributing factors to the total resistance.

The resistance of the device at high forward current levels is composed of three terms: the contact resistance of the metal contacts, the bulk spreading resistance in the highly-doped substrate layer, and the bulk spreading resistance in lightly-doped "active region". Of course the relative importance of these factors is strongly dependent upon the geometry of the device, particularly the metal contact size and the sample thickness and carrier concentrations in the GaP layers. Several graphs have been prepared to illustrate the applicable ranges of values for the problem of interest here.

In Fig. 1, the contact resistance is shown as a function of the diameter, d, of a circular contact for several different values of "specific contact resistance", r_c. As can be seen, provided that the value of r_c is less than 10^{-3} Ω-cm^2 (a reasonable value for metal-semiconductor systems) the contact resistance is less than 2 ohms for dot diameters greater than 250 microns.

The spreading resistance in the substrate material is presented in Fig. 2. Again for reasonable values of resistivity (e.g., the tellurium doped GaP with a carrier concentration of 2×10^{17} has a

resistivity of 0.3 Ω-cm with a conductivity mobility of 100 cm^2/volt-sec, the substrate spreading resistance contributes only a few ohms to the total value for thicknesses on the order of 200 microns and dot diameters greater than 250 microns.

The principal area of concern appears to be the spreading resistance in the lightly-doped epitaxial region. The problem essentially is that the carrier concentration must be sufficiently low to insure the high breakdown voltage required. At that low carrier-concentration, the resistivity is quite high. Furthermore the epitaxial layer must be sufficiently thick that "punch-through" does not occur, i.e., at the maximum reverse operating voltage the actual epitaxial layer must be greater than the depletion layer thickness. These parameters are seen in Figs. 3 and 4.

In Fig. 3, for example, at a breakdown voltage of 350 volts, the carrier concentration must be less than 3×10^{15} cm^{-3}.[2] At that carrier concentration the depletion layer using the abrupt approximation[3] is approximately 11 microns. From Fig. 4, $n = 3 \times 10^{15}$ corresponds to a resistivity of 21 Ω-cm.

To calculate the spreading resistance the correction factor "B" can be used,[4] such that

$$R_s = \frac{\rho}{2d} B.$$

Values of B for various dot diameters and material thicknesses are given in Fig. 5.

To continue the illustration, Fig. 6 gives the appropriate values of spreading resistance as a function of dot diameter. For a dot diameter of 250 microns, the value of spreading resistance for 21 Ω-cm material, 11 microns in thickness, is off-scale and is in fact approximately 46 ohms. The spreading resistance for this case, the thinnest possible epitaxial layer having a breakdown voltage greater than 350 volts, is not less than 5 ohms until the dot diameter is greater than 700 microns.

A final contribution to the total resistance should be mentioned. It can be termed a "residual resistance" and includes such external factors as a mounting case resistance or lead resistances. The residual resistance should be negligible in comparison to the other terms.

In summary, the bulk spreading resistance of the epitaxial layer appears to be the most important single factor in the overall device resistance. The layer must be kept as thin as possible and the GaP must be of sufficiently uniform crystalline quality that the contacts may be made adequately large in diameter.

Plans for Next Quarter

Further work will be continued on the examination of the contact problem in GaP and in the growth of undoped GaP in the vertical liquid epitaxial system.

References

1. Y. Nannichi and G. L. Pearson, Solid State Electronics 12, 341 (1969).

2. S. M. Sze and G. Gibbons, Appl. Phys. Letters 8, 111 (1966).

3. A. S. Grove, Physics and Technology of Semiconductor Devices, John Wiley and Sons (New York 1967) p. 159.

4. R. H. Cox and H. Strack, Solid State Electronics 10, 1213 (1967).

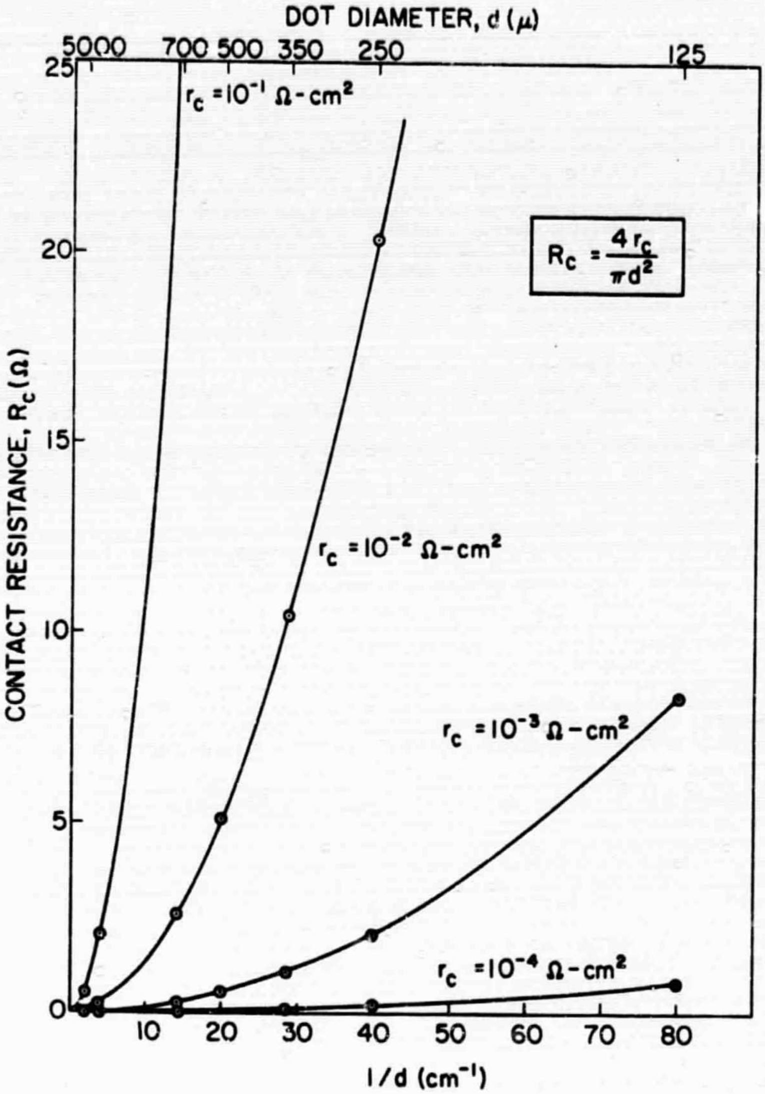

Fig. 1 - Contact resistance as a function of dot diameter, d, for various values of specific contact resistance, r_c .

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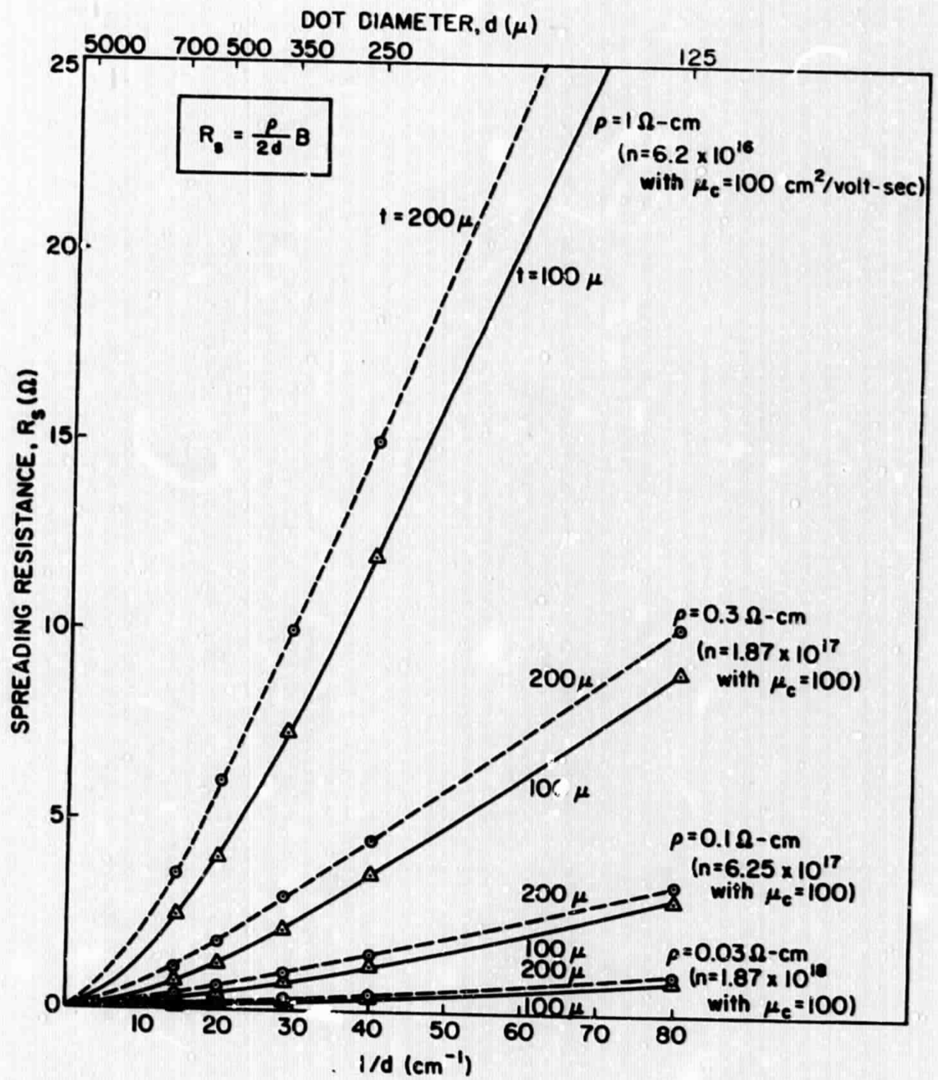

Fig. 2 - Spreading resistance, R_S, as a function of dot diameter, d, at 100 micron and 200 micron thickness for typical values of substrate resistivity

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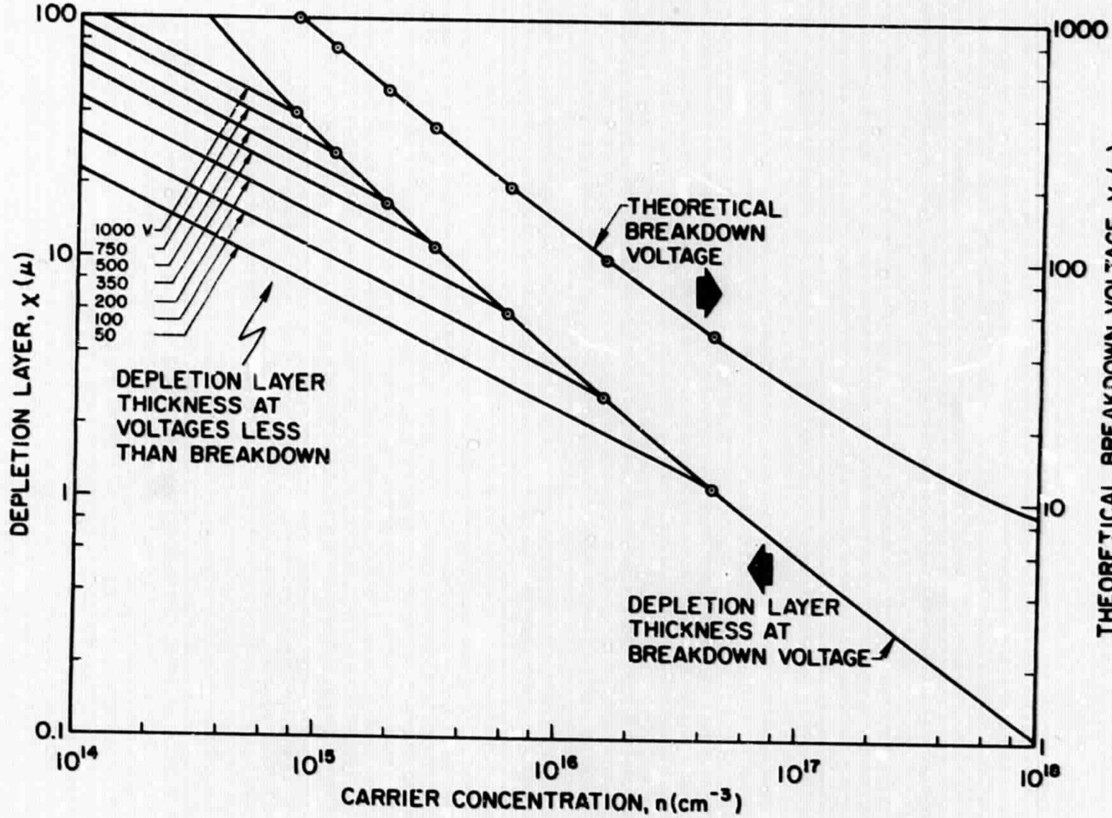

Fig. 3 - Theoretical breakdown voltage and depletion layer thickness of GaP as a function of carrier concentration.

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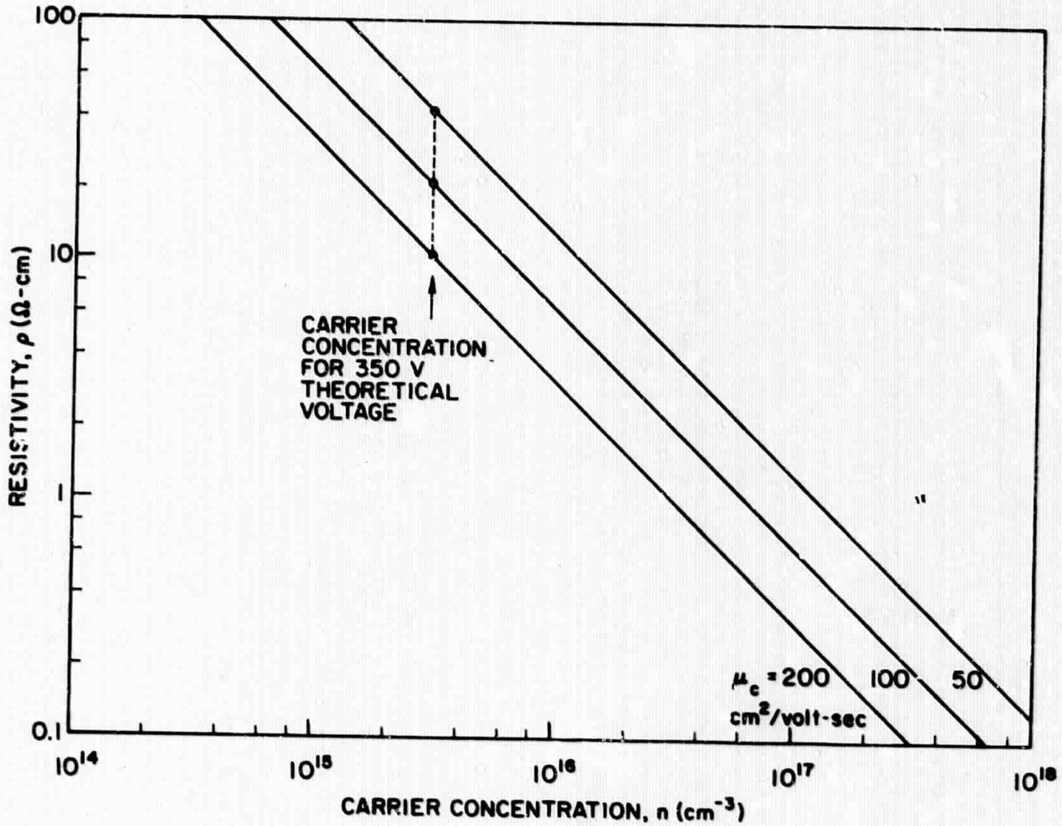

Fig. 4 - Bulk resistivity of GaP as a function of carrier concentration for selected conductivity mobilities.

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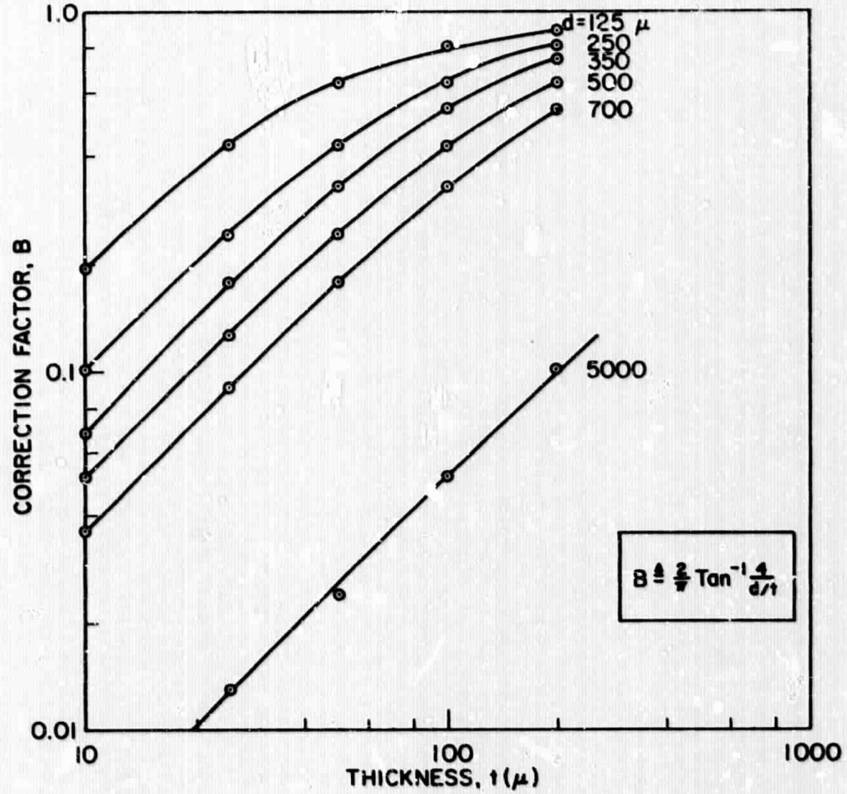

Fig. 5 - Spreading resistance correction factor, B, as a function of material thickness for selected dot diameter.

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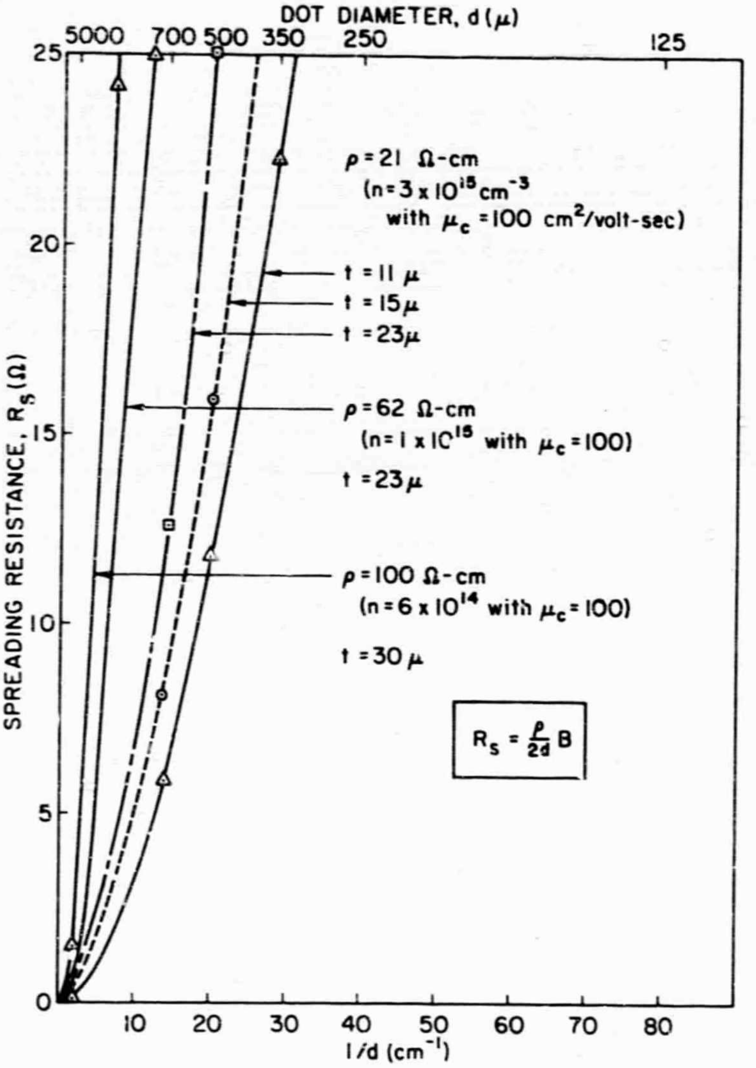

Fig. 6 - Spreading resistance, R_S, as a function of dot diameter, d, at various material thicknesses and resistivities such that voltage breakdown, V_B, ≥ 350 volts.

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